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RESEARCH NOTE

A Judd illusion in far-aiming: evidence of a contribution to action by vision for perception

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Abstract The present study addresses the role of vision for perception in determining the location of a target in far-aiming. Participants ($N = 12$) slid a disk toward a distant target embedded in illusory Judd figures. Additionally, in a perception task, participants indicated when a moving pointer reached the midpoint of the Judd figures. The number of hits, the number of misses to the left and to the right of the target, the sliding error (in mm) and perceptual judgment error (in mm) served as dependent variables. Results showed an illusory bias in sliding, the magnitude of which was comparable to the bias in the perception of target location. The determination of target location in far-aiming is thus based on relative metrics. We argue that vision for perception sets the boundary constraints for action and that within these constraints vision for action autonomously controls movement execution, but alternative accounts are discussed as well.

Keywords Ventral system · Dorsal system · Far-aiming · Judd-illusion

Introduction

Goodale and Milner's (1992) proposal that the dorsal and ventral systems can be distinguished by the functional demands that they serve in action and perception, has explicated a confusion of neurophysiological and behavioral observations. Nevertheless, contributions to action by the ventral system, if any, are not clearly understood (Glover 2004; Milner and Goodale 2008). Hence, rather than addressing the distinction between vision for perception and vision for action,[1] we aimed to assess the role of vision for perception in the course of action. To this end, we investigated a far-aiming task that was modeled on a traditional Dutch sport called shuffle-boarding ('sjoelen'), in which players slide disks toward a distant target.

According to Milner and Goodale vision for perception serves to obtain knowledge about the environment, using information that specifies objects and their properties in relation to surrounding objects in relative metrics. They further argued that vision for action supports movement control and relies on information that specifies objects in absolute metrics. Research using visual illusions has shown that perception of object properties, such as size and location, depends strongly on visual context, attesting to the use of relative metrics. Movement control, in contrast, remains relatively unaffected by visual context, suggesting that absolute metrics are used (Agliotti et al. 1995; Ganel et al. 2008). The role of vision for perception, however, is not confined to perception. Milner and Goodale (2008) (van der Kamp et al. 2008) argued that the perception or identification of action goals and the selection of an appropriate action entail key contributions from vision for perception. For example, van Doorn et al. (2007) (see also Crajé et al.

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[1] We only obtained behavioral data. Hence, our claims are restricted to behavior and are necessarily suggestive with respect to the underlying neural circuitry. We use 'vision for perception' and 'vision for action' to refer to the behavioral processes of detecting and using visual information for perception and action.

2008) recently demonstrated that in picking up relatively large objects the choice of either a one- or a two-handed grasp is affected by an illusion. The control of hand aperture, however, remained unaffected. In short, vision for perception and action appear to serve distinct yet complementary functions in action. Vision for perception sets the boundary constraints for action, and within these constraints the movements are autonomously controlled by vision for action (Milner and Goodale 2008).

The present study addresses the roles of vision for perception and action in aiming toward a target. In particular, we asked what type of information is used to determine the location of a target. One conjecture is that target location is specified relative to its context. That is, vision for perception determines the target location relative to adjacent objects in the environment and sets this location as the boundary constraint for action. Informed by vision for perception, vision for action subsequently exploits (egocentric) information that specifies this target location in absolute metrics to the actor (Gentilucci et al. 1996). Inaccurate aiming would reflect errors in the initial determination of target location by vision for perception. An alternative conjecture is that vision for action independently (i.e., without engagement of vision for perception) uses instantaneous information pertaining to the target location in relation to the actor, without taking the broader visual context into account. For movement control, this may be more efficient than relying on 'delayed' target location information provided by vision for perception (Westwood and Goodale 2003).

Unlike far-aiming, near-aiming, especially pointing, is well-researched in this context. In the typical study, participants make pointing movements to the endpoints of a line embedded in illusory surroundings, such as a Müller-Lyer figure (e.g., Gentilucci et al. 1996). A recent review of the extant literature on pointing revealed that under full-vision conditions (i.e., with both the target and the hand in view) endpoint accuracy is largely immune to illusory configurations. Only when vision of the target is removed (particularly before movement onset) does significant movement bias occur (Bruno et al. 2008). In full vision, however, aiming reflects movement control that is based on target location information that is coded egocentrically in absolute metrics (e.g., the gap between hand position and target location). This online control is attributed to vision for action.

Importantly, in near-aiming, control of hand position is possible until contact is made with the target. Hence, analysis of only endpoint accuracy (as in Bruno et al.'s (2008) review) leaves doubts about whether determination of target location engages vision for perception. It would be more convincing to study pointing with no opportunity for participants to view their hand, or the target, during movement execution (Westwood and Goodale 2003). In visual open-loop conditions, initial errors in perceived target location cannot be annulled by online vision for action control as the movement unfolds. Yet, these conditions still allow propriocepsis to reduce pointing error. Moreover, Gentilucci et al. (1996) reported that in full vision the Müller-Lyer figure affected the entire kinematics of the pointing movement (although the precise scope of the bias is difficult to quantify). This observation led Gentilucci et al. (1996) to speculate that initial aiming was based on information comprising visual context.

Contrary to near-aiming, in far-aiming (e.g., sliding a disk toward a distant target) movement control (both visual and proprioceptive) is necessarily confined to the moment the object is released. Hence, the issue of the type of information that (i.e., absolute or relative) is used to determine target location may be more appropriately resolved using far- rather than near-aiming tasks. Two studies speak to this point, but provide ambiguous results. Glover and Dixon (2004) had participants step and hop from one end of a Müller-Lyer figure to the other end under full vision. A small illusion effect (<3%) was discerned, but its magnitude might have been reduced by the moving body occluding the target, especially in the stepping task. More recently, van der Kamp and Masters (2008) reported that throwing accuracy in handball is influenced by the goalkeeper's posture. Notably, the goalkeeper mimicked an amputated Müller-Lyer figure by raising the arms skyward (i.e., outward Müller-Lyer figure), stretching them to the side (i.e., neutral figure) or pointing them downward (i.e., inward figure). These goalkeeper postures affected the perceived size of the goalkeeper in accordance with the Müller-Lyer illusion. Intriguingly, participants threw the ball further from the goalkeeper when the arms were raised skywards than when the arms were stretched to the side. However, when the arms were pointing downward, the ball was not thrown closer to the goalkeeper. Although this might suggest a reliance on visual context, it cannot be ruled out that the effects of goalkeeper posture on throwing accuracy are related to factors other than the illusory size of the goalkeeper (e.g., the arms up goalkeeper may look more aggressive).

To further investigate what type of information defines the target location in far-aiming, we asked participants to slide a disk over the exact midpoint of a line that was embedded in a Judd figure. We assumed that influences of visual context (i.e., the arrowheads) are indicative for the use of relative metrics, pointing to contributions from vision for perception rather than vision for action (Ganel et al. 2008). We hypothesized that if there is a role for vision for perception in far-aiming, then sliding accuracy will be biased by the illusion.

Method

Participants

Twelve right-handed undergraduates of the University of Hong Kong (mean age 21.6 years, SD = 1.3) volunteered to participate. They were treated in accordance with the local institution's ethical guidelines and gave written consent prior to the experiment.

Material

Participants were seated in front of a table (1.52 m in length and 1.37 m in width). Three visual targets were used, consisting of black lines embedded in a Judd figure with the arrowheads pointing to the right or to the left, or without arrowheads. Commonly, the arrowheads affect perception of the midpoint of the line such that the perceived midpoint is shifted to the right for arrowheads pointing to the left and vice versa. The lines, which were printed on a sheet of paper, measured 0.08 m in length and 0.02 m in width, while the arrowheads were 0.02 m in length and had an inclination of 45° to the line. The targets were placed in the middle of the table or 0.02 m to the right or left of the middle, at a distance of 1.2 m from the front edge of the table, where the participant was seated. A red block (0.01 × 0.01 × 0.01 m) served as the target during practice trials. A Chinese chequer disk (0.02 m in diameter and 0.01 m in height) served as the projectile. Two pre-calibrated cameras of a QualisysTM 3-D motion capture system recorded the trajectory of the disk at 100 Hz. Reflective tape made the disk visible. There were two reference markers at the edges of the table aligned with the target.

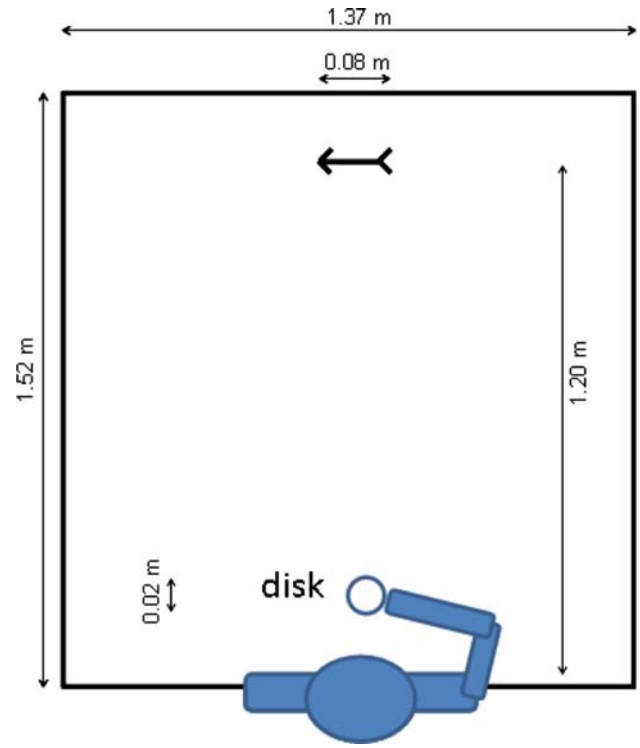

Fig. 1 Schematic representation of the experimental set-up (i.e., not to scale). Depicted is a Judd left figure in the mid position

Procedure and design

The participants performed an action and a perception task. For the action task, the participants started with a series of 100 practice trials. They were instructed to aim the disk at the red target block by making a sliding action. Participants observed the experimenter produce the sliding action to become acquainted with how to hold, move and release the disk. After the practice trials, the participants were instructed to propel the disk over the exact midpoint of the target line that was presented on the table top (Fig. 1). They made a total of 90 sliding actions to 3 different target lines (i.e., line without arrowheads ('control'), line with Judd figure arrowheads pointing to the left ('Judd left') and line with arrowheads to the right ('Judd right')) at three positions (i.e., middle of the table and 0.02 m to the right or left, from the middle). The 9 conditions were presented in blocks of 10 trials, the order of which was randomized across participants. The participants propelled the disks one at a time and at their own pace. Short rest intervals were provided between blocks.

For the perception task, the experimenter moved a pointer slowly behind the line from the left to the right (and vice versa in the other half of the trials). The participants were told to say 'stop' when they perceived that the pointer was at the exact midpoint of the line. Participants were allowed to alter their estimate if they had second thoughts about its correctness. The experimenter then marked the estimated midpoint on the sheet. A fresh sheet was used for each estimate. The same 9 conditions (i.e., same target lines and positions) as in the action task were used. They were presented in blocks with the order randomized across participants. Each condition was presented 4 times, resulting in 36 trials. Finally, the order of the perception and action tasks was counterbalanced between participants.

Data analysis

For the action task, the trajectory of the disk was used to compute the location, where the disk crossed the target line. Sliding error was defined as the difference (in mm) between this location and the midpoint of the line. If absolute sliding error was smaller than 10 mm (i.e., the disk touched the midpoint) a hit was scored, otherwise a miss to the left (i.e., error <−10 mm) or to the right (i.e., error >+10 mm) was scored. For the perception task, the judgment error was

Table 1 Mean (SD) for sliding error (mm), number of hits, misses to left and right, and estimate error (mm)

	Judd left	Control	Judd right
Sliding error	−6.1 (9.3)	−12.5 (8.3)	−12.6 (3.9)
Hits	6.9 (2.6)	5.1 (3.1)	6.3 (2.4)
Miss to left	13.0 (3.3)	15.3 (2.9)	15.9 (1.4)
Miss to right	10.0 (2.7)	9.7 (2.7)	7.7 (2.3)
Estimate error	2.0 (1.1)	−0.3 (1.0)	−2.3 (0.6)

defined as the difference (in mm) between the estimated and the actual midpoint. We submitted both the sliding error and the perceptual judgment error to an ANOVA (Target: control, Judd left and Judd right) with repeated measures. The number of hits and the number of misses to the left and right were examined using a MANOVA (Target: control, Judd left and Judd right) with repeated measures. Post-hoc comparisons were made using Tukey-HSD, and η_p^2 was used as the measure of effect size. Finally, the difference between the Judd right and Judd left figures for the sliding and perceptual judgment errors served as indicators for the illusory bias in the action and perception tasks, respectively. *T* tests were used to assess whether the bias differed from zero.

Results

For the action task, the participants generally aimed to the left of the midpoint of the target line, but less so when it was embedded in the Judd left figure (Table 1). The ANOVA confirmed that sliding error was significantly influenced by Target ($F(2,22) = 4.07$, $p < 0.05$, $\eta_p^2 = 0.27$). Post-hoc tests indicated differences in error between the Judd left and Judd right figures and between the Judd left and control figures, but not between the Judd right and control figures. Figure 2 presents the illusory bias for each individual participant. Ten out of twelve participants showed a bias, with a mean bias of 6.4 mm (SD = 9.0 mm) that significantly differed from zero ($t(11) = 2.46$, $p < 0.05$).

Similar to sliding error, the MANOVA on the performance measures revealed a significant effect of Target (Wilks $\Lambda = 0.54$, $F(6,40) = 2.37$, $p < 0.05$, $\eta_p^2 = 0.26$). Separate ANOVAs indicated that the illusion did not affect the number of hits ($F(2,22) = 1.86$). The misses were significantly affected by the illusion. Participants missed more to the left of the midpoint when aiming at the Judd right and the control figures than when aiming at the Judd left figure ($F(2,22) = 5.54$, $p < 0.05$, $\eta_p^2 = 0.34$). Conversely, participants missed more to the right when aiming at the Judd left and control figures than when aiming at the Judd right figure ($F(2,22) = 4.00$, $p < 0.05$, $\eta_p^2 = 0.27$) (Table 1).

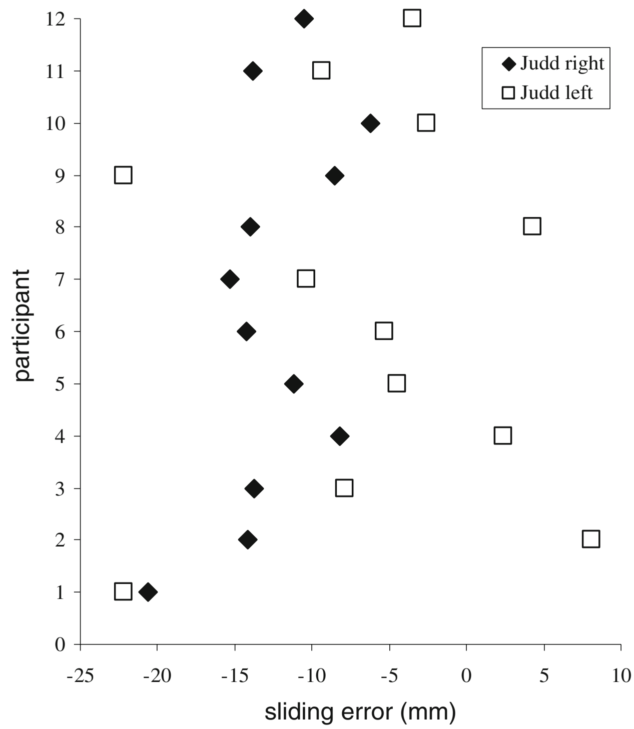

Fig. 2 The illusory bias in aiming for each individual participant. A bias occurred in all but two participants (i.e., 1 & 9)

For the perception task, the ANOVA indicated a significant main effect of Target ($F(2,22) = 94.5$, $p < 0.001$, $\eta_p^2 = 0.90$). Post-hoc tests showed that the midpoint estimates for each of the figures differed. The average illusory bias was 4.3 mm (SD = 1.3), which significantly differed from zero ($t(11) = 11.7$, $p < 0.001$). Finally, a comparison of the magnitudes of the illusory bias in the perception and action tasks did not reveal a significant difference ($F(1,11) = 0.64$). A Pearson-product correlation, however, failed to show a significant relationship between the two biases ($r(12) = -0.24$, $p = 0.48$).[2]

Discussion

This study provided evidence of a contribution to action by vision for perception. Sliding accuracy toward the midpoint of the distant target showed a significant illusory bias.[3] The determination of target location thus strongly depended on information that specifies the midpoint in relation to its visual surrounding (i.e., arrowheads) in relative metrics,

[2] Exclusion of the two participants with a negative illusory bias in action still resulted in a nonsignificant correlation ($r(10) = 0.41$, $p = 0.12$).

[3] In fact, only the Judd left figure differed significantly from the control figure. Perusal of the literature shows that this observation is not uncommon (e.g., Fleming and Behrmann 1998), but we found no explanation for this asymmetry.

indicating that vision for perception can indeed be engaged in action. Prior work has already pointed to a role of vision for perception in the choice of action goals and action modes (for overview see Milner and Goodale 2008). The present study further delineates this role of vision for perception in action by suggesting that it also contributes to the determination of target location. This does not imply that the distinction between vision for perception and vision for action becomes superfluous, nor does it prove that it is correct (Smeets et al. 2002; Vishton et al. 1999). Effects of visual context persist only when online movement control is minimized or perturbed, such as in far-aiming or visual open-loop conditions (Post and Welch 1996). In full-vision conditions, errors in perceived target location are rapidly reduced during movement execution by vision for action. Ellis et al. (1999), for example, found that the location at which a bar was grasped was not systemically distorted by the Judd illusion (see also Gentilucci et al. 1996).

Vickers (1992) recorded gaze in participants performing far-aiming tasks like golf putting and basketball shooting. Information about the target, especially its exact location was picked up prior to, rather than during movement execution. Vickers argued that the duration of the final target fixation reflects the time needed for movement parameterization. She envisioned that target information stipulates the parameterization of the pre-programed movement kinematics (see Glover 2004). In contrast, rather than prescribing the movement kinematics, we argue that target location information obtained by vision for perception acts as a boundary constraint on vision for action. It is within these boundary constraints that vision for action instantaneously sets up and controls the kinematics of the movement in real-time (Westwood and Goodale 2003). Admittedly, however, we cannot distinguish the validity of these two alternative accounts based on the present findings. Further work is needed to determine how vision for perception and action interact during the course of an action.

One critical factor that may influence the extent to which vision for perception contributes to action is skill level (Gonzalez et al. 2008; van der Kamp et al. 2003, 2008). An important distinction between novice and skilled performers is the degree of conscious control of the action. It is plausible that the more consciously an action is controlled, the more likely it is that it engages vision for perception. Gonzalez et al. (2008), for example, found that unfamiliar awkward grips were much more susceptible to a size-contrast illusion than the precision grips that participants habitually used to grasp small objects. The present participants were all novices.[4] Hence, the illusory bias might have been markedly smaller, had the participants been skilled shuffleboarding players.

The illusory biases in the action and perception tasks were not identical nor were they correlated, suggesting that the tasks induced somewhat disparate contributions from vision for perception. One possible distinction is that in the action task the target location (i.e., midpoint of the line) was visually available relative to the visual surroundings only (i.e., endpoints of the line), while in the perception task the moving pointer may have provided additional contextual information. Previously, Post and Welch (1996) found that the illusionary bias in pointing to the midpoint of a line within a Judd figure disappeared when a short line was added to mark the midpoint. Yet, the moving pointer in the present study does not necessarily provide more *veridical* information for the midpoint. Hence, it is unlikely that this informational difference between the present tasks caused a larger reliance on relative metrics in the action than in the perception task. In any case, the present findings do underline the role of vision for perception in action for far-aiming tasks that are not uncommon. It is akin to directing a soccer penalty kick *inside* the uprights of the goal rather than *at* the uprights or placing a tennis serve *in* the back right corner of the service box rather than *at* the lines. It remains to be seen whether the present findings generalize to targets that are visually more directly specified. Another observation that suggests disparate contributions from vision for perception in the two tasks is that participants slid the disk slightly to the left of the midpoint of the line. A similar leftward bias is reported for adults in line bisection tasks, where participants indicate the midpoint of a line (McCourt and Garlinghouse 2000). Noticeably, this leftward bias only presented itself during the far-aiming task, but not when participants perceptually judged the midpoint of the line. This difference might be related to space being perceived differently within or beyond the action space. Longo and Lourenco (2006) demonstrated that the leftward bias in a line bisection task disappeared, or shifted to the right, when the line is placed out of reach of the observer. However, when the participant used a tool (i.e., a stick), thereby expanding the action space, the leftward bias also occurred for larger distances. Similarly, sliding a disk to a distant target might have expanded the participants' action space, resulting in a leftward bias in aiming toward the target, but not when perceiving its midpoint.

In summary, mapping the contribution of vision for perception to action is conditional for understanding how vision for perception and vision for action interact. In this respect, we found an illusory bias when a projectile was aimed toward a distant target, providing evidence for a contribution to action by vision for perception. This makes a great deal of sense given that determining target

[4] This is suggested by the mean within-participant standard deviation for the sliding error being much higher than for the perceptual judgment error (i.e., 40.1 mm vs. 9.9 mm).

location in far-aiming (e.g., inside the base-line) is tightly linked with identifying action goals (e.g., hitting the tennis ball down-the-line or cross-court) and selecting an appropriate action mode (e.g., fore- or back-hand), both of which involve vision for perception. Further investigation is needed to define how the two visual processes interact.

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